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An Evaluation of the Psychophysical Phenomenon upon Application of Sensory Stimuli to the Periodontal Ligaments of Mandibular Teeth

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AN EVALUATION OF THE PSYCHOPHYSICAL PHENOMENON UPON APPLICATION OF SENSORY STIMULI TO THE PERIODONTAL LIGAMENTS OF MANDIBULAR TEETH

BY

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AUTOBIOGRAPHY

John G. Bonaguro was born in Chicago, Illinois, November 10, 1941. He graduated from Mendel High School in Chicago in June, 1959. He attended St Thomas College in St. Paul, Minnesota for three years form September, 1959 to June, 1962. In June, 1966 he received his Doctor of Dental Surgery degree from Loyola University in Chicago. For the last two years he has been in attendance at the Loyola University Graduate School, Department of Orthodontics. He was married to the former Marilyn Hornick in April, 1964. He has a son James, and a daughter Jeanne.

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CHAPTER I

INTRODUCTION AND STATEMENT OF THE PROBLEM

In the past, numerous studies have been concerned with the sensory output of the periodontal ligament as measured along some aspect of the trigeminal nerve. However, only two studies have concerned themselves with the ability of an individual to consciously discriminate differences in the magnitude of sensory stimuli applied to the teeth.

The purpose of this study is to determine the ability of young adults to quantitatively discriminate force stimuli applied to the mandibular central incisor, lateral incisor, canine, and premolar teeth. This will be done by establishing that the Psychophysical Law (Weber-Fechner Law) can be used to measure discriminatory ability in these teeth, and then determining the optimal range of intensity over which it operates.

CHAPTER II

REVIEW OF THE LITERATURE

Weber's Law

In his historical development of the Weber-Fechner Law, Hecht (1924) wrote that Bouguer (1760) made observations of his ability to detect the shadow cast by one candle when the screen upon which the shadow fell was simultaneously illumunated by another candle. The two candles projected shadows of a rod upon the white screen, and then one candle was moved away from the screen until its projected shadow was first noticable against the background of the screen. Bouguer found that the ratio of the two intensities at the point on the screen was 1/64 or 1.5 per cent. In other words, the shadow was first noticable when the far candle was eight times as far from the screen as the near candle. This ratio did not change, for any pair of distances at which the two candles were adjusted, or when the brightness of the candles varied. In a repeat of Bouguer's experiments, Masson (1845), reported that although people gave different values for the ratio $\Delta I/I$, the ratio was constant for a given person regardless of the intensity or color.

Boring (1950) wrote that Weber (1834) discovered for the sense of touch that one could discriminate between two weights if they differed by 1 or 2 parts in 30. Weber made it clear that the smallest perceptible difference between two weights could be stated as a ratio that was independent of the magnitudes of the weights. He later conducted other weight, visual, and sound experiments and discovered the ratios that represented the least perceptible differences were: weights, 1/40; lines, 1/50 or 1/100; and tones, 1/60. However, he did not formulate any specific law. This was done by Fechner.

Fechner (1854), while working with lifted weights, noticed that there must be a large enough difference between the two weights before they could be distinguished as being different. In 1858 he repeated Bouguer's experiments with two candles and a shadow, and demonstrated $\Delta I/I$ to be uniformly 1/100. Based on his own observations and those of Bouguer and Weber, Fechner devised a ratio between the sensory stimulus and the change in this stimulus before a difference in the two could be detected. He assumed that the "just noticable difference" of sensation always contained the same number of sensation units. He felt that this ratio was maintained along the entire scale of sensory stimuli, and was, therefore, a constant.

Although he recognized Bouguer's priority, Fechner (1860) referred to this ratio as Weber's Law. This law stated that the ratio between the detectable change in intensity of a stimulus and the intensity of the stimulus equals a constant. He stated this mathematically as $\Delta I/I = C$.

James (1890) concluded that Weber's Law was true as an emperical generalization, and that the Weber Ratio could be found for measurable senses. The ratios he gave were: light, 1/100; sound, 3/10; pressure and muscle sense, 1/40; and warmth and taste, 1/3. However, he felt Weber's Law only held true for an intermediate range of stimuli, and that it increased above and below this range. He did not agree with Fechner's psychological interpretation of Weber's Law, and felt that the Law had only a purely physiologic value.

Knight (1922) beleived the Weber Ratio to be theoretically interesting, but not workable in practical cases. He based his beliefs on: (1) the limited range of the Weber Ratio, (2) that the physical and psychological condition of the subjects must be approximately constant, and (3) because it only applied to intensities.

Hecht felt that Weber's Law was true, but that it only applied to a narrow range of the intensity scale. In his light experiments on the eye of Mya arenia (the clam) he found that as the intensity of the light rose, the Weber Ratio at first decreased and than later increased. He was critical of Fechner for saying that Weber's Law was a constant at the extremes of the intensity scale. Hecht expressed belief that sensory judgements were relative, not absolute.

Thurstone (1927) felt that Weber's and Fechner's Laws were independent of each other, and should not be referred to jointly as the Weber-Fechner Law. He stated that one could be applicable to a set of data while the other was not. Thurstone defined Weber's Law by saying that the stimulus increase that is correctly discriminated in 75 per cent of the attempts is a constant fraction of the stimulus magnitude when only two judgements or their equivalent were allowed.

Steinhardt (1936) agreed with Hecht that as the intensity of a stimulus increased, the Weber Ratio showed a substantial decrease.

Van Leeuwen (1949), while working with the response of muscle spindles in the frog, reported that Weber's law was a property of a single stretch receptor. However, a large number of results had to be taken into account because random fluctuations so invalidated single observations that the relation was not clear.

Pieron (1952) also felt that Weber's Law only applied to the intermediate range of intensities, and that near threshold or physiologically tolerable limits the ratio increased. He further stated that Weber's Law was verified on a purely physiological basis, but had no psychological basis as Fechner applied to it.

Fulton (1955) stated that Weber's Law applied to most sensory modalities, but only over a very limited range of intensities. He criticized the generality that Fechner applied to Weber's Law.

Kawamura and Watanabe (1960) compared the discriminatory ability of patients with natural and artificial dentitions by having the patients bite down on small stainless steel wires placed between the teeth. They found the Weber Ratio in the human natural dentition to be 0.1 in both the incisor and molar areas. This ratio increased in those patients with artificial dentitions.

Treisman (1963 and 1964) agreed with previous investigators that the Weber Ratio held true for the middle ranges of many different types of sensory stimuli, but tended to increase at the high and low extremes of intensity.

Grossman (1965) tested oral tactile sensitivities by using small filaments in a aesthesiometer, and applying the procedure of "just noticable difference". He reported the areas of greatest oral tactile sensitivity in the following order: (1) upper lip; (2) tongue; (3) lower lip; and (4) incisive papilla.

Nakfoor (1967) tested the maxillary central incisor with controlled pressure stimulation of patients undergoing active orthodontic treatment. He found that the Weber Ratio was a constant over the middle ranges of intensity, but increased at both the lower and higher ends of the scale. This was in agreement with the findings of Hecht, Exner, Wundt, Fulton, and Treisman. He established a Weber Ratio for these teeth of 0.10 to 0.15 which compared favorably with the findings of Kawamura and Watanabe of 0.1.

Fechner's Law

Fechner formulated the Psychophysical Law which stated that sensation increased as the logarithm of the intensity of the stimulus increased. He expressed this mathematically as $S = A \log I + K$, where S equalled the intensity of the sensation in sensation units. On a logarithmic scale, I, the intensity of the stimulus increased in a straight line starting from the Y intercept K. The slope of this line was represented by the constant A.

Delboeuf (1872), Broca (1894), and Helmholtz (1924), while working with light, concluded that sensation increased proprtionately to the logarithm of the intensity of the stimulus.

James (1890) did not believe in the validity of Fechner's Law. He stated that although the law was of mathematical and metaphysical interest, it had no basis in psychology. He attacked Fechner's assumption that the "just noticable difference" was a sensation unit, and that all of our sensations consisted of sums of these units. James felt that sensations could not be measured numerically, and that Fechner's attempts to do so were pure matematical speculation.

Munsterberg (1894) studied the ability of subjects to visually estimate the differences in lengths of lines. He believed in the validity of Fechner's Law. However, in his experiments he used the psychometric method of measuring psychophysical phenomena rather than the method of "just noticable difference" which he felt was theoretically questionable.

Waller (1895) maintained that Fechner's Law controlled the excitatory processes of the retina of the eye, muscles, and nerves. He found that the electrical response of the retina increased as the logarithm of the stimulating illumination increased in the middle region of intensities, but that inflections occurred at low and high intensities. Thus he felt that an S - shaped (sigmoid) curve must be substituted for the logarithmic straight line.

Thurstone (1929) found Fechner's Law to be applicable only to those stimulus series in which the attribute being judged could also be physically measured. Although he felt the psychophysical Law was independent of Weber's Law, he stated that the law demanded some respect since it held true for so many measurable stimulus series. He also found that practice on the part of the experimental subjects increased the proportion of correct judgements and aided in the construction of a psychophysical scale.

Matthews (1931 and 1933) found that the frequency of impulses from muscle spindles was approximately proportional to the logarithm of the load on the tendon within two seconds after loading. This only occurred at moderate tensions. At higher tensions, the muscle spindle fell short of this proportionality.

Hartline and Graham (1932) studied the effect of light on the lateral eye of the horseshoe crab. They found that over a moderate range of intensities the frequency of discharge of impulses from the nerve of the eye had a linear relationship to the logarithm of the intensity of the stimulus, thus paralleling the findings of Matthews for the muscle spindle.

Guilford (1932) stated that Fechner's Law was only true for the middle ranges of stimulus intensity. He also felt that the formula proposed by Cattell and Fullerton, $\Delta R_a = (KR_a)^{.5}$, was not completely true. He maintained that both Fechner's and Cattell's Laws were simplified and special cases of a more generalized power function which he calculated as being $\Delta R_a = K\ R_a{}^n$. He stated that this power law took care of small values of R where Fechner's Law did not hold true.

Houstoun (1932) wrote that Helmholtz found Fechner's Law to apply to the medium ranges of illumination, but that its validity was upset at the upper and lower limits of intensity.

Pfaffman (1939), while investigating the mechanoreceptors of the maxillary incisor, canine, and premolar of the cat, found that the relationship between the frequency of response and the stimulus was approximately logarithmic over a limited range of intensities. The high and low limits of this range were 20 and 200 grams respectively.

Ness (1954), while studying the mechanoreceptors in the periodontal ligament of the rabbit mandibular incisor, found that the response of these fibers as recorded on the dental nerve was linearily related to the logarithm of the magnitude of the stimulus. This only occurred for forces below 100 grams.

In the past, many men have opposed Fechner's Law on the grounds that the relation between sensory intensity and stimulus intensity could be expressed more accurately as a power function. These men included Plateau (1850), Bretano (1874), Grotenfelt (1888), Guilford, and Stevens (1957 and 1960).

Stevens has been the greatest critic of Fechner's Psychophysical Law in modern times. He has demonstrated on 14 Class I or prothetic continua (those having to do with <u>how much</u>) that the psychological magnitude is a power function of the stimulus magnitude. He felt that the sensation was proportional to the stimulus raised to a power, and proposed the following equation: $dS = k\ I^x$. In these 14 continua, he found the exponents to range from 0.33 for brightness to 3.5 for electric shocks applied to the finger. Stevens felt that Fechner's Law was not found to be true experimentally because the indirect resolving power (just noticable difference) was not constant in psychological units as Fechner had assumed, but was proportional to the psychological magnitude.

Treisman (1961) stated that both Fechner's logarithmic law and Stevens' power law were valid. However, he felt that a central neural response - determining process as described by the logarithmic function of Fechner was simpler and more useful than one using the power function.

Brett (1962) listed the objections to Fechner's Law as being: (1) the laws and formulae of psychophysics lacked support of experimental evidence; (2) the law only had physiologic value; (3) the mathematical expression of Fechner's was wrong; and (4) that mental processes were biological rather than mathematical as advocated by Fechner.

Nakfoor (1967), working with discrimination of forces applied to the maxillary central incisors, found that the power function of Stevens fit his data better than did Fechner's logarithmic equation. He found that for forces applied to the incisal surface and directed along the long axis of the tooth, the results could best be described by the equation $dS = 0.23\ I^{.861}$. For forces applied to the labial surface and directed at 90° to the long axis of the tooth, the results were best described by the equation $dS = 0.24\ I^{.865}$. Nakfoor further established that a near linear relationship existed in the range of forces between 50 and 500 grams, but that forces of 10 and 1000 grams fell outside the optimal limits of the psychophysical phenomenon.

Functional Innervation of the Periodontal Ligament

Peaslee (1857) stated that the teeth were affected by touch stimuli, and were able to localize these stimuli. He felt that the teeth were most sensitive on their masticatory surfaces.

Black (1887) said that the sense of touch resided wholly in the periodontal tissues, while the pulp yielded only painful responses.

Noyes (1921) wrote that the sensation of touch for the teeth rested entirely in the periodontal ligament, and that the only function of the nerves of the periodontal ligament was to convey sensations of proprioception. He further stated that all nerves of the periodontal ligament terminated in beaded free endings, and that no special nerve endings were present.

Stewart (1927) conducted minimal pressure and localization experiments on the labial surfaces of incisors and canines. His results showed that the threshold of 260 teeth tested varied between 7 and 250 grams per square mm. He found that pulpless teeth gave the same results as normal teeth, and concluded that the transmission of pressure stimuli was not a function of the pulpal nerves, but resided entirely in the nerves of the periodontal ligament. He also found that the teeth had the ability to localize pressure stimuli. In both his pressure and localization experiments, the canine was the most sensitive tooth.

Van der Sprenkel (1935) described the innervation of the periodontal ligament as consisting of apical fibers following the path of the blood vessels, and alveolar fibers arising from the interdental areas. The alveolar fibers supplemented the apical fibers, and then both groups of fibers proceeded gingivally together. Van der Sprenkel found three types of endings for the myelinated nerves of the periodontal ligament. The first were small end rings which functioned in pressure perception and localization. The second were the terminal reticula, the significance of which he did not know. Lastly, he found unmyelinated fibers that penetrated the dentin and cementum of the teeth. He hypothesized that these fibers might be sensitive to changes in the shape of the teeth due to compression of the dentinal tubules during function. It can be noted here that no other investigators have been able to identify nerve fibers of the periodontal ligament penetrating either the dentin or cementum.

Lewinsky and Stewart (1936) studied the periodontal ligament innervation of both the human and cat. They agreed with Van der Sprenkel that the nerves of the periodontal ligament arose from the apical region, proceeded along the course of the blood vessels, and were reinforced by fasciculi which entered the periodontal ligament through the foramina in the alveolar process. As these fibers proceeded gingivally they gave off terminal branches that ended in fine arborizations throughout the periodontal ligament. Some of these terminal fibers had knob-like endings. They were unable to trace any nerve fibers into the cementum of the teeth.

Brashear (1936) felt that pressure sensations to the teeth were only transmitted along the large sized nerve fibers of the periodontal ligament. These fibers were 10 to 16 microns in diameter, and made up 24 per cent of the total nerve fibers counted. However, he felt that touch was not the only sensation elicited by the periodontal ligament because of the presence of all different sizes of nerve fibers. He stated that temperature sensations were carried by the medium sized fibers 6 to 10 microns in diameter, and that pain was mediated along small myelinated and unmyelinated nerve fibers that were less than 6 microns in diameter.

Pfaffman found that when the full nerve trunk supplying the maxillary incisor, canine, and premolar of the cat was placed on the sensory electrodes, pressure against any surface of a tooth elicited about the same response. A single fiber, however, was only affected by pressure against a particular surface of a tooth. From this position of maximum stimulation, there was a decrease in stimulating efficiency until a position of about 90° on either side was reached where the stimulus was no longer effective for that particular fiber.

Pfaffman also described two types of nerve fibers in the periodontal ligament. The first were large fibers of 10 to 14 microns in diameter, and consisted of 20 per cent of all the fibers present. He felt these fibers carried impulses of pressure. He stated that the smaller nerve fibers of 2 to 9 microns in diameter carried painful impulses.

Orban (1944) agreed with Van der Sprenkel, and Lewinsky and Stewart on the distribution of nerve fibers in the periodontal ligament. He felt there were three types of nerve fibers in the periodontal ligament. The first were the free nerve endings that conducted painful impulses. Secondly were those that formed loops or rings around the bundles of principle fibers of the periodontal ligament to which he assigned no function. Lastly, there were knob-like swellings that functioned in proprioception and localization of pressure stimuli.

Ness stated that the receptors responding to pressure applied to the crowns of the teeth were located in the periodontal ligament. He divided these mechanoreceptors into slow adapting, fast adapting, and spontaneously discharging depending on the spike sizes of their nervous discharges. Of these, the slow adapting receptors had the greatest directional sensitivity. He found that the most sensitive direction was inciso-apically, and felt that this could be due to the orientation of the individual receptors in the periodontal ligament.

Dockrill (1954) noted that hair follicles, whisker follicles, and teeth all had the same basic nerve pattern consisting of thicker myelinated and thinner non-myelinated fibers. He felt that this similarity of nervous distribution might be due to the fact that these structures were all of ectodermal origin.

Loewenstein and Rathkamp (1955) studied pressure thresholds of vital teeth by applying forces on the teeth at the incisal and occlusal surfaces. Their average threshold was 2.523 grams with a range of 0.948 grams on the maxillary central incisor to 5.030 grams on the mandibular first molar. They felt that the higher threshold observed on the posterior teeth was due to the greater surface area of the roots of these teeth. A significant finding of these men was that the threshold of pulpless teeth was 57 per cent higher than in normal teeth. From this they concluded that there were intradental as well as periodontal pressorecptors. This was in disagreement with the previous investigations of Stewart and Pfaffman.

Bernick (1957) agreed with Van der Sprenkel, and Lewinsky and Stewart in regard to the origin, direction, and location of nerve fibers in the periodontal ligament. He also found that the terminal branches of the medullated nerves ended in non-medullated, elongated, spindle-like structures that were found primarily around the apical 1/3 of the root.

Kawamura and Watanabe, while comparing the Weber Ratios of natural and artificial dentitions, concluded that the periodontal ligament was necessary to make finite judgements in the size of materials placed between the upper and lower teeth.

Kizior (1966) found two types of sensory endings in the periodontal ligament of the cat incisor, and concluded from this that these endings had two different functions. The first were highly organized, encapsulated, ovoid endings that were the terminations of the larger nerve fibers in the periodontal ligament. These were located around the apical 1/3 of the root. He felt these endings were sensitive to pressure stimuli, and reached their action potentials upon application of light forces to the teeth. The second type were the free nerve endings which he felt were sensitive to pain. These nerves had a much higher threshold than the ovoid endings. He also noted that the periodontal ligament receptors had directional sensitivity, with the incisal edges being the most sensitive areas.

Nakfoor noticed no directional sensitivity when applying pressure stimuli to the labial surface and incisal edge of maxillary central incisors of children undergoing active orthodontic treatment. From this he concluded that the proprioceptive nerve endings were evenly distributed throughout the periodontal ligament as shown by Lewinsky and Stewart, rather than being confined to the apical 1/3 area as shown in Kizior's study of the cat incisor.

CHAPTER III

METHODS AND MATERIALS

Introduction

The thirty subjects used for this experiment were graduate students at Loyola's Orthodontic Clinic and the Loyola Dental School. They ranged in age from 24 to 33 years old.

Subjects selected for this study had to meet the following requirements. The age limitations placed on the patients was from 20 to 35 years. It was found that most subjects fell into the 24 to 30 year old range. The most important criteria for limiting the selection of experimental subjects was that they must not have received orthodontic treatment earlier in their lives.

The occlusion of the teeth did not play an important role in the selection of experimental subjects. The only requirement here was that the mandibular anterior teeth had a reasonably normal horizontal overbite and vertical overbite relationship, and that no spacing be present between the teeth to be tested. Therefore, it was found that most individuals with either an Angle Class I or Class II first molar relationship were acceptable for the study. Angle Class III individuals were not acceptable because of the reverse horizontal overbite relationship of their anterior teeth.

The teeth tested were the mandibular central incisor, lateral incisor, canine, and first premolar on either side of the arch for each test subject. The data collected was obtained from readings of forces applied to the labial surface and incisal edge of the central incisor, lateral incisor, and canine, and to the buccal surface of the first premolar.

A pilot study was conducted on five second year graduate orthodontic students. This pilot study determined the magnitude of force application used in this study. The subjects used in this pilot study were later retested, and the data obtained from them was included in the final experimental results.

<u>Force Producing Instrument</u>

The force producing instruments used in this research were torque wrenches manufactured by the P. A. Sturtevant Company, Elmhurst, Illinois, (Figure 1).

A torque wrench is a device used to measure resistance to a turning force. The components are (Figures 2 and 3):

A) drive square

B) a flexible beam

C) handle

D) scale

E) force indicator

Figure 1.--Torque Wrenches

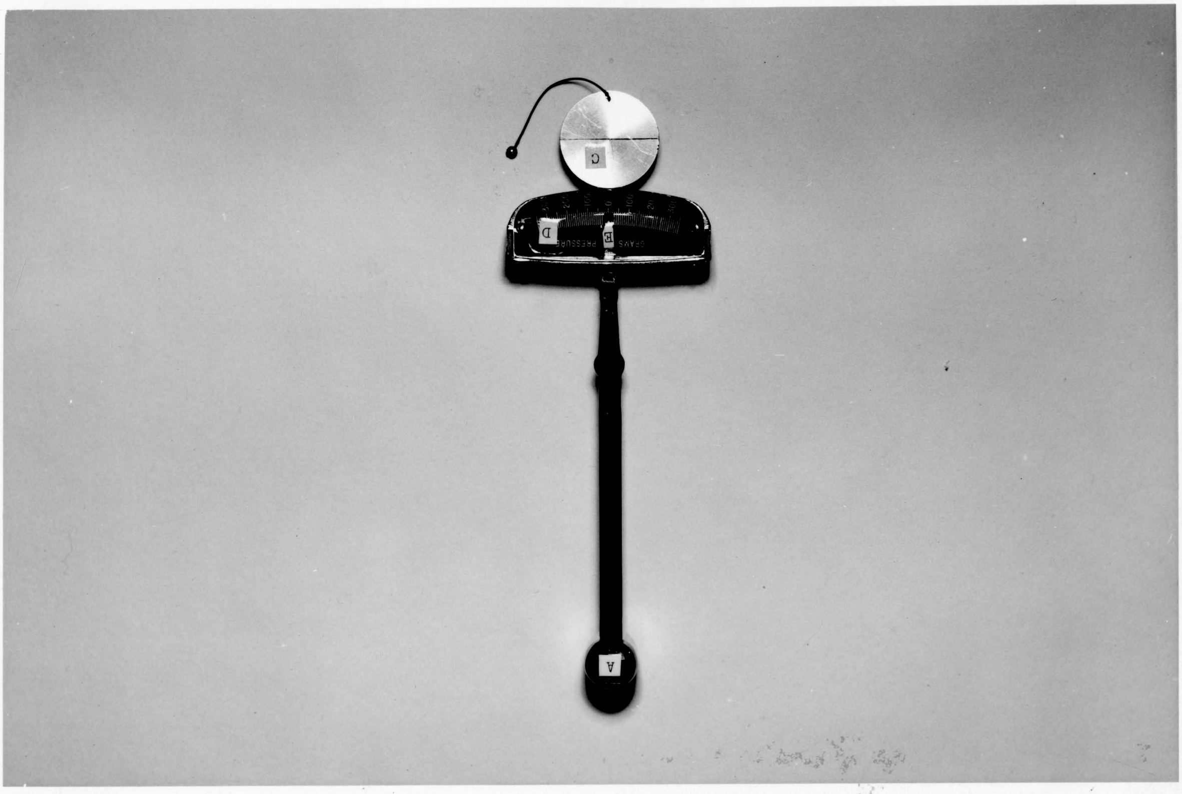


Figure 2.--Torque Wrench

A. Drive Square
B. Flexible Beam
C. Handle
D. Scale
E. Force Indicator

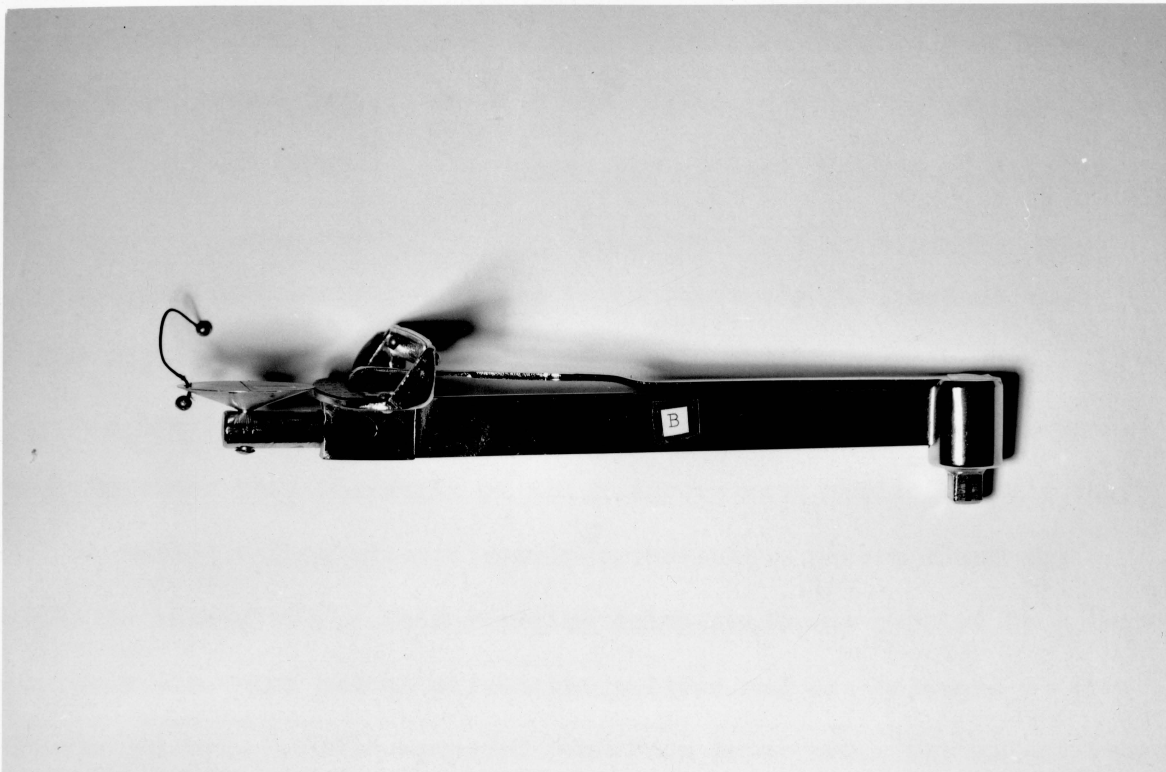


Figure 3.--Torque Wrench

A. Drive Square
B. Flexible Beam
C. Handle
D. Scale
E. Force Indicator

By applying a force at the handle of the instrument, a torque is produced at the drive square end. The magnitude of the torque can be computed by the mathematical expression, $T = F \times D$, the Torque Law. T expresses torque, F indicates force, and D is the distance through which the force is applied. (beam length). The torque Law governs the use of a torque wrench.

To measure torque, a torque wrench must always function upon another object. In this particular case, the object was a tooth.

A bearing and drive shaft assembly was adapted to the torque wrench in order that the angle at which forces were applied to the teeth could be varied. This allowed nearly frictionless movement and the ability to rotate 360°. This rotating drive shaft was coupled to a twelve inch lever arm which had an adjustable pointer and was balanced at the opposite end by a counter-weighted four inch lever arm. The relationship of the pointer to the long axis of the tooth being tested determined the direction in which the force was applied to the tooth. The pointer could be adjusted to any desired position on the tooth.

All forces were applied by the index finger and thumb of the examiner's right hand. This satisfied the Torque Law by insuring that force application was perpendicular to the torque wrench beam, and also concentrated all the force at one point on the handle of the wrench. It further allowed standardization of the experimental procedure. Upon application of heavier forces of 1000 grams or more, the left hand was used to push the right wrist, and thus all forces were still applied through the handle of the torque wrench.

The torque wrench calibrations were certified with a maximum allowable error that did not exceed 2 per cent of the full scale readings. Force values ranging from 0 to 3000 grams were used to stimulate the teeth in this experiment.

The four torque wrenches used in this experiment were calibrated as follows:

1) 0 - 70 grams, in 2 gram increments.
2) 0 - 350 grams, in 5 gram increments.
3) 0 - 1500 grams, in 50 gram increments.
4) 0 - 3000 grams, in 100 gram increments.

The above forces were the range of forces applied to the teeth through the drive shaft and lever arm. The force reading can be explained by the Torque Law, $T = F \times D$. When solving for F (force), the equation is expressed as $F = T/D$.

The torque force was produced at the drive square and transmitted through the drive shaft and ball bearing assembly. This was delivered to the teeth by means of a fiber or plastic tip attached to the lever arm, and was called the "compressive" force. This force varied inversely with the length of the lever arm. For example, if a 350 inch gram torque was extended the full scale range, and had a one inch lever arm from the center of the drive shaft, then 350 grams of "compressive" force would be exerted. Mathematically this could be expressed as:

$$T = F \times D$$

$$350 \text{ in gm} = F \times 1 \text{ in}$$

$$F = \frac{350 \cancel{\text{in}} \text{ gm}}{1 \cancel{\text{in}}}$$

$$F = 350 \text{ gms}$$

The extension of the pointer tip to twelve inches from the center of the drive shaft would only generate 29.16 grams of compressive force with full deflection of the 350 in gm torque wrench. This would be stated mathematically as:

$$T = F \times D$$

$$350 \text{ in gr} = F \times 12 \text{ in}$$

$$F = \frac{350 \cancel{\text{in}} \text{ gm}}{12 \cancel{\text{in}}}$$

$$F = 29.16 \text{ gms}$$

The calibrated scales on the torque wrenches were marked to give direct readings of the compressive force on the teeth in grams when the twelve inch lever arm was used. The length of the lever arm did not change during the experiment.

The tip of the pointer used on the labial surface of the tooth was a cylindrical piece of solid polyetholene vinyl plastic attached to the metal tip of the pointer by means of a centered hole half way through the cylinder. The tip of the pointer used on the incisal edge of the tooth was a piece of the same cylindrically shaped vinyl plastic imbedded in methylmethacrolate plastic with a tapered oval configuration, and with a rectangular cut on the opposite end of the cylinder. This cut prevented the pointer from slipping from the incisal edge when force was applied. (Figure 4).

The fixture from which the torque wrench was suspended allowed additional versatility by means of adjustable parts. (Figure 5). The iron base measured 48 inches by 18 inches, and weighed approximately 300 pounds. Located centrally on the rear one-fifth of this base was an adjustable iron pipe which projected upward at 90° to the base, and measured 48 inches. A conventional dental headrest, that was placed on the cranial portion of the head, was attached to this post and was used as a "head holder".

An extension arm, 48 inches high, paralleled the fixed post. Two right angled arms braced the extension arm to the fixed post. One arm was an iron extension and the second was a soldered joint; and both were adjustable in a horizontal direction. The bottom brace was also adjustable in a vertical direction.

A 36 inch adjustable vertical arm ran perpendicular to the extension arm. The torque wrench assembly was securely fastened to this vertical arm.

The major horizontal and vertical adjustments were accomplished

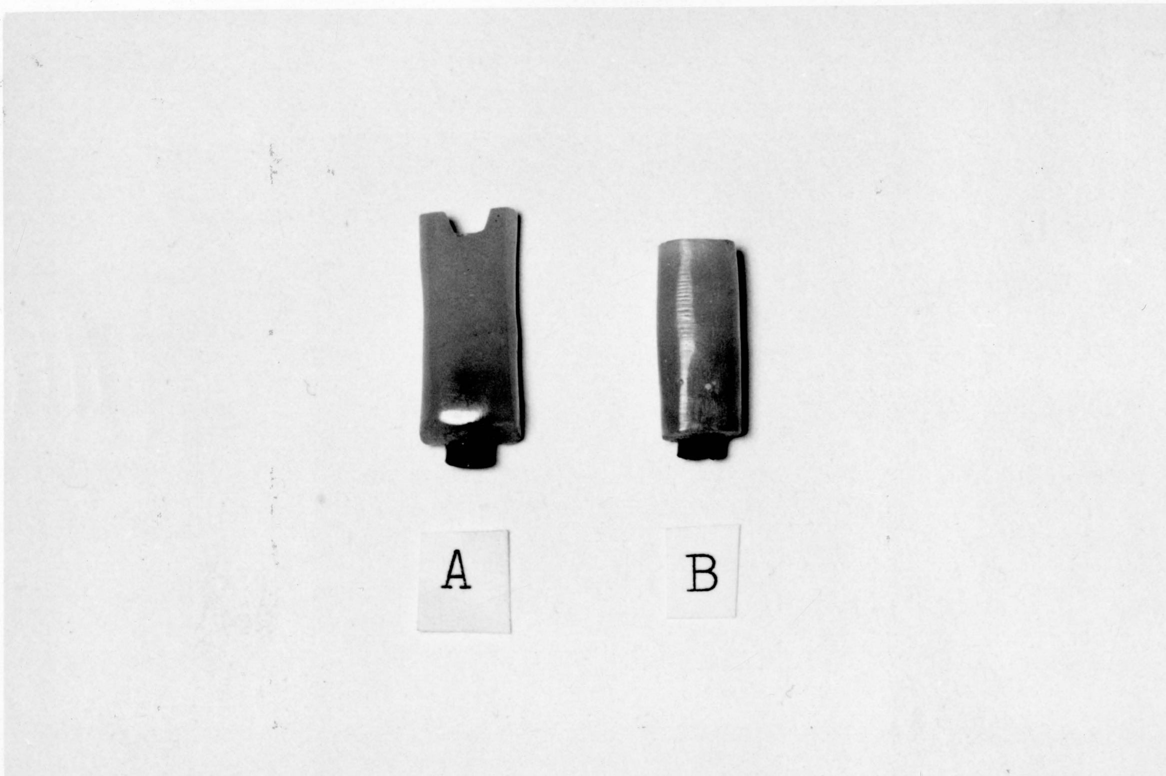


Figure 4.--Stimulating Tips

A. Along Long Axis
B. 90° to Long Axis (Labial or Buccal Surface)

Figure 5.--Torque Wrench Assembly and Dental Chair

by a perpendicular adjustable assembly holding these arms. This was a soldered couple with thread screws to secure the desired position.

With the versatility of the torque wrench assembly, and the numerous horizontal and vertical adjustable areas of the fixture, any sized patient or any desired position could be handled.

It was necessary to stabilize the mandible by means of a stereotaxic instrument. This consisted of the chin rest portion of an S. S. White Panorex radiograph unit that was modified to attach to the arms of the orthodontic treatment chair that was used. (Figure 6). When applying force to the labial and buccal surfaces of the teeth tested, the dental headrest was placed on the posterior cranial portion of the skull to further stabilize the head and mandible. It was not necessary to use the headrest when taking the incisal readings since the chin rest provided sufficient stabilization.

Experimental Procedure

The examining room was a study room in the orthodontic department. It was seven feet square, well lighted, and air-conditioned. The metal base of the force producing apparatus sat in the middle of the room. The examiner was seated to the left side of the patient while examining the incisors, and in back of the patient while applying forces to the canines and premolars.

The patients were seated in an orthodontic treatment chair. The

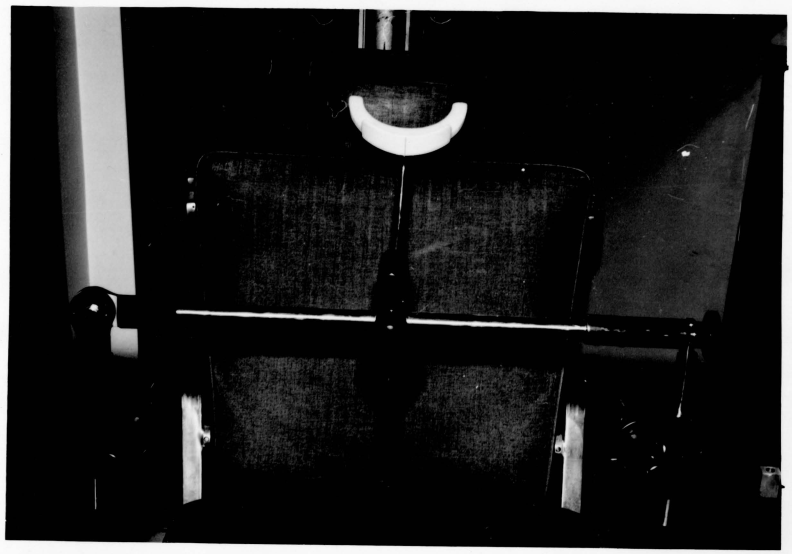


Figure 6.--Chin Rest

chair had an adjustable headrest, an adjustable back, stationary arms to which the mandibular chin rest was attached, and a foot controlled hydraulic pump. The center of the headrest of the chair was positioned against the fixed vertical post.

After the patients were seated in the chair and the necessary adjustments made on the force producing instrument, the procedure was explained to them. They were told that two forces were to be applied to the labial (buccal) and incisal surfaces of specific teeth, and that these forces would be identified by the words "first" and "second" as the forces were applied. They were asked to identify which of the forces was heavier. It was stressed to the experimental subjects that they should not guess which forces were heavier. This was necessary because even with pure guesswork they had a 50 per cent chance of being correct, and this could affect the results.

The standard force values used on the incisors were 50 grams, 100 grams, 200 grams, 500 grams, 1000 grams, 1500 grams, and 2000 grams. Those used on the canines and premolars were 100 grams, 200 grams, 500 grams, 1000 grams, 1500 grams, 2000 grams, and 2500 grams. The differential threshold was established with each of these force ranges for each tooth of every subject. This was accomplished by first using a differential threshold of plus and minus 10 per cent of the standard values, and then increasing or decreasing these forces, as was necessary for the individual subject, when comparing it to the standard values. After the subject's differential threshold was determined, its validity was established. This was done by asking the individual to correctly identify the heavier of the two forces at least seven out of ten times. These forces were administered in random order.

If the subject could not correctly identify the heavier force 70 per cent of the time, the differential threshold was considered too low and was then increased for the subject. The differential threshold was increased above the previously determined differential threshold until the subject could identify the heavier of the two forces at seven out of ten times. This value was then considered as the differential threshold for that subject.

If the subject correctly identified the heavier force ten times out of ten times, the determined differential threshold was considered too high, and a new lower differential threshold was established. This was accomplished by decreasing the force differential compared to the standard force value. The subject was then required to identify the heavier force, in random order, seven or more times out of ten, but less than ten times out of ten.

The differential threshold was checked above and below the standard force values because the sensation of these two segments were not always the same. As an example, at 50 grams, 46 grams may be distinguishable, but 56 grams or 58 grams may be required before they are distinguishable from 50 grams.

The subjects' replies were recorded immediately after they were stimulated and asked to identify the heavier force.

The results of both the 90° to the long axis and the long axis recordings were then plotted on semi-logarithmic graph paper and full logarithmic graph paper. For uniformity, established differential thresholds were plotted along the abscissa (Y - axis), and the standard force values were plotted along the ordinate (X - axis).

The same procedure was followed for the subsequent recordings on all subjects.

Miscellaneous

It was found to be difficult for the experimental subjects to verbally relate which of the forcees were heavier. Therefore, different hand signals were used by the subjects to give their information to the examiner. Either hand was used. If the first force was felt to be the heavier of the two, the fore-finger was extended. If the second force was felt by the subject to be heavier, then both the fore-finger and middle finger were extended. If the subject could not distinguish any difference between the two forces, they gave a waving motion with their hand.

The apparatus for stabilizing the mandible caused fatigue among the experimental subjects after several sets of readings were taken. Therefore, all of the readings could not be taken at one time. They were usually recorded at three different sessions. There was no set way of dividing the readings between the three recording sessions.

The duration of tooth stimulation was considered important since this could affect a subject's response to the stimuli. It was found that within limits the lighter force could be judged to be the heavier force if it was applied for a longer duration than the heavier force. Therefore, it was necessary to develop a rhythm that permitted nearly equal time intervals for both the standard force and its differential threshold.

CHAPTER IV

FINDINGS

The forces used in this investigation varied between 50 grams and 2000 grams for the mandibular central and lateral incisors, and 100 grams to 2500 grams for the mandibular canine and first premolar.

In general, all of the teeth tested demonstrated a more linear relationship when the logarithm of the differential threshold was plotted against the logarithm of the applied force. A straight line relationship was not as evident when the actual value in grams of the differential threshold was plotted against the logarithm of the applied force. (Figures 7, 8, 9, and 10). However, in all cases this relationship was not nearly as linear as that observed in Nakfoor's study of the maxillary central incisor.

A further generalization that can be made is that these teeth have very poor tactile discriminatory powers at low force values. This was demonstrated by the high Weber Ratios at applied forces of 50 grams, 100 grams, and 200 grams on the central and lateral incisors, and at 100 grams and 200 grams of applied force on the canine and first premolar. (Table 1). The Weber Ratios observed at these applied forces were all higher than those observed by Nakfoor. In all cases, the Weber Ratios decreased in the intermediate ranges, and then began to rise at the higher values. (Table 1).

On the central incisor, lateral incisor, and canine teeth, both the labial and incisal surfaces were tested. It was found that the two surfaces had nearly the same range of discrimination with regard to the actual values in grams employed, although there was a statistically significant difference between the labially and incisally applied forces as indicated by the Student "t" Test. (Table 2). Discrimination of forces applied to the labial surface was slightly better than for the incisal surface at all readings for both the lateral incisor and canine. (Figures 8 and 9). This was not evident for the central incisor. In fact, discrimination was better for forces applied to the incisal surface than for forces applied to the labial surface at force values of 500 grams, 1000 grams, and 2000 grams. (Figure 7).

The high standard deviations seen for the central incisor at applied forces of 50 grams and 100 grams on both the incisal and labial surfaces indicates a wide range of individual variation. (Table 1). The "t" comparisons of the Weber Ratios for the various force standards were significant at the .001 level for all applied force values with the exceptions of 500 vs. 1000 grams, 500 vs. 1500 grams, and 1000 vs. 1500 grams on the labial surface, and 500 vs. 1000 grams on the incisal surface. (Table 3). The log differential threshold in grams plotted against the log of the applied force in grams showed that the optimal range of the Weber Ratio had an upper limit near 1500 grams, and a lower limit of between 200 grams and 500 grams. (Figure 7).

The lateral incisor also displayed high standard deviation values at applied forces of 50 grams and 100 grams on both the incisal and labial surfaces. (Table 1). The "t" comparisons of the Weber Ratios between the various force standards were also statistically significant at the .001 level with the exceptions of 500 vs. 1500 grams on both the labial and incisal surfaces. (Table 4). It should be noted that the Weber Ratios recorded for this tooth were higher than those seen on the central incisor, except at applied forces of 500 grams and 1000 grams on the labial surface. (Table 1). The log-log plot of this tooth indicated that the upper limit of the psychophysical phenomena was near 1500 grams, while the lower limit occurred between 200 grams and 500 grams of applied force. (Figure 8).

The canine showed a high standard deviation at an applied force of 100 grams on both the labial and incisal surfaces. (Table 1). The "t" values of comparisons between the Weber Ratios were all significant at the .001 level with the exception of the 500 vs. 2000 gram, 500 vs. 2500 gram, and 1000 vs. 1500 gram comparisons on the labial surface, and 500 vs. 2500 grams, 1000 vs. 1500 grams, and 1000 vs. 2000 grams on the incisal surface. (Table 5). The Weber Ratios recorded for the canine were the lowest of any tooth tested. (Table 1). The log-log graph indicated that the lower limit of the Weber Ratio occurs between 200 grams and 500 grams. The upper limit was not as well defined on the graph, and probably exceeds 2500 grams which was the highest applied force used. (Figure 9).

The first premolar showed high standard deviation values at applied forces of 100 grams and 200 grams. (Table 1). The "t" comparisons of the Weber Ratios between the various force standards were statistically significant at the .001 level with the exception of the 500 vs. 2500 gram, 1000 vs. 1500 gram, and 1000 vs. 2000 gram comparisons. (Table 6). This tooth had the highest overall Weber Ratios recorded, although the central and lateral incisor teeth often had higher ratios at some of the heavier applied forces such as 1500 grams. (Table 1). The log - log plot indicates that the lower limit of the optimal range for the Weber Ratio began at about 500 grams. The upper limit was not well defined as in the canine, and may exceed the 2500 gram force that was used. (Figure 10).

TABLE 1

Mean Weber Ratios ± One Standard Deviation for Conscious Discriminatory Thresholds of Forces Applied to the Mandibular Central Incisor, Lateral Incisor, Canine, and First Premolar

Central Incisor

Applied Force	Weber Ratio Labially Directed	Weber Ratio Incisally Directed
50 grams	.517±.188	.573±.196
100 grams	.343±.122	.358±.155
200 grams	.211±.0891	.214±.0809
500 grams	.143±.0599	.130±.0466
1000 grams	.146±.0925	.127±.0470
1500 grams	.142±.0745	.147±.0435
2000 grams	.161±.0589	.160±.0541

Lateral Incisor

Applied Force	Weber Ratio Labially Directed	Weber Ratio Incisally Directed
50 grams	.613±.196	.633±.188
100 grams	.387±.179	.428±.150
200 grams	.241±.0928	.269±.0891
500 grams	.142±.0605	.153±.0557
1000 grams	.125±.0578	.138±.0578
1500 grams	.142±.0550	.148±.0560
2000 grams	.164±.0657	.174±.0638

Canine

Applied Force	Weber Ratio Labially Directed	Weber Ratio Incisally Directed
100 grams	.355±.151	.410±.161
200 grams	.215±.0928	.247±.0910
500 grams	.138±.0654	.152±.0610
1000 grams	.117±.0463	.129±.0491
1500 grams	.122±.0423	.131±.0473
2000 grams	.131±.0402	.136±.0399
2500 grams	.141±.0435	.153±.0495

First Premolar

Applied Force	Weber Ratio Buccally Directed
100 grams	.415±.189
200 grams	.258±.114
500 grams	.160±.0700
1000 grams	.137±.0557
1500 grams	.137±.0455
2000 grams	.146±.0516
2500 grams	.165±.0557

TABLE 2

"t" Comparisons of Weber Ratios Between Labially Applied Forces and Incisally Applied Forces to the Mandibular Central Incisor, Lateral Incisor, and Canine

Central Incisor		Lateral Incisor	
Applied Force	"t" Value	Applied Force	"t" Value
50 grams	6.080***	50 grams	2.172*
100 grams	2.242*	100 grams	5.177***
200 grams	.733	200 grams	6.422***
500 grams	5.058***	500 grams	3.943***
1000 grams	5.398***	1000 grams	4.693***
1500 grams	1.706	1500 grams	2.256*
2000 grams	.369	2000 grams	3.226**

Canine

Applied Force	"t" Value
100 grams	7.353***
200 grams	7.273***
500 grams	4.620***
1000 grams	5.240***
1500 grams	4.186***
2000 grams	2.604*
2500 grams	5.381***

* .05>P>.01

** .01>P>.001

*** P<.001

TABLE 3

"t" Comparisons of Weber Ratios for Various Forces Applied to the Labial and Incisal Surfaces of the Mandibular Central Incisor

Labial		Incisal	
Applied Force	"t" Value	Applied Force	"t" Value
50 vs. 100 grams	22.955***	50 vs. 100 grams	25.324***
50 vs. 200 grams	43.466***	50 vs. 200 grams	50.850***
50 vs. 500 grams	55.988***	50 vs. 500 grams	64.672***
50 vs. 1000 grams	53.327***	50 vs. 1000 grams	65.109***
50 vs. 1500 grams	54.745***	50 vs. 1500 grams	62.372***
50 vs. 2000 grams	53.373***	50 vs. 2000 grams	59.768***
100 vs. 200 grams	25.832***	100 vs. 200 grams	24.283***
100 vs. 500 grams	43.573***	100 vs. 500 grams	41.455***
100 vs. 1000 grams	37.958***	100 vs. 1000 grams	42.000***
100 vs. 1500 grams	41.529***	100 vs. 1500 grams	38.574***
100 vs. 2000 grams	39.738***	100 vs. 2000 grams	35.484***
200 vs. 500 grams	18.733***	200 vs. 500 grams	26.582***
200 vs. 1000 grams	14.910***	200 vs. 1000 grams	27.358***
200 vs. 1500 grams	17.513***	200 vs. 1500 grams	21.474***
200 vs. 2000 grams	13.812***	200 vs. 2000 grams	16.364***
500 vs. 1000 grams	.802	500 vs. 1000 grams	1.333
500 vs. 1500 grams	.309	500 vs. 1500 grams	7.870***
500 vs. 2000 grams	6.316***	500 vs. 2000 grams	12.397***
1000 vs. 1500 grams	.995	1000 vs. 1500 grams	9.217***
1000 vs. 2000 grams	4.403***	1000 vs. 2000 grams	13.580***
1500 vs. 2000 grams	5.901***	1500 vs. 2000 grams	5.532***

* $.05 > P > .01$

** $.01 > P > .001$

*** $P < .001$

TABLE 4

"t" Comparisons of Weber Ratios for Various Forces Applied to the Labial and Incisal Surfaces of the Mandibular Lateral Incisor

Labial		Incisal	
Applied Force	"t" Value	Applied Force	"t" Value
50 vs. 100 grams	25.111***	50 vs. 100 grams	25.123***
50 vs. 200 grams	50.612***	50 vs. 200 grams	51.558***
50 vs. 500 grams	67.770***	50 vs. 500 grams	72.072***
50 vs. 1000 grams	70.520***	50 vs. 1000 grams	73.991***
50 vs. 1500 grams	68.360***	50 vs. 1500 grams	72.823***
50 vs. 2000 grams	64.143***	50 vs. 2000 grams	68.000***
100 vs. 200 grams	21.345***	100 vs. 200 grams	26.904***
100 vs. 500 grams	38.222***	100 vs. 500 grams	50.832***
100 vs. 1000 grams	65.620***	100 vs. 1000 grams	60.417***
100 vs. 1500 grams	38.522***	100 vs. 1500 grams	51.661***
100 vs. 2000 grams	34.467***	100 vs. 2000 grams	46.098***
200 vs. 500 grams	26.400***	200 vs. 500 grams	32.584***
200 vs. 1000 grams	31.267***	200 vs. 1000 grams	36.288***
200 vs. 1500 grams	27.049***	200 vs. 1500 grams	33.989***
200 vs. 2000 grams	19.948***	200 vs. 2000 grams	25.606***
500 vs. 1000 grams	5.986***	500 vs. 1000 grams	5.515***
500 vs. 1500 grams	00.000	500 vs. 1500 grams	1.866
500 vs. 2000 grams	7.261***	500 vs. 2000 grams	7.317***
1000 vs. 1500 grams	6.273***	1000 vs. 1500 grams	3.663***
1000 vs. 2000 grams	13.131***	1000 vs. 2000 grams	12.329***
1500 vs. 2000 grams	7.560***	1500 vs. 2000 grams	9.028***

* $.05 > P > .01$

** $.01 > P > .001$

*** $P < .001$

TABLE 5

"t" Comparisons of Weber Ratios for Various Forces Applied to the Labial and Incisal Surfaces of the Mandibular Canine

Labial: Applied Force	Labial: "t" Value	Incisal: Applied Force	Incisal: "t" Value
100 vs. 200 grams	23.295***	100 vs. 200 grams	25.997***
100 vs. 500 grams	38.889***	100 vs. 500 grams	44.178***
100 vs. 1000 grams	44.403***	100 vs. 1000 grams	49.212***
100 vs. 1500 grams	43.797***	100 vs. 1500 grams	49.033***
100 vs. 2000 grams	42.264***	100 vs. 2000 grams	48.754***
100 vs. 2500 grams	40.150***	100 vs. 2500 grams	45.009***
200 vs. 500 grams	20.000***	200 vs. 500 grams	25.606***
200 vs. 1000 grams	27.841***	200 vs. 1000 grams	33.618***
200 vs. 1500 grams	26.879***	200 vs. 1500 grams	33.333***
200 vs. 2000 grams	24.419***	200 vs. 2000 grams	32.840***
200 vs. 2500 grams	21.264***	200 vs. 2500 grams	26.781***
500 vs. 1000 grams	7.721***	500 vs. 1000 grams	8.647***
500 vs. 1500 grams	6.038***	500 vs. 1500 grams	8.015***
500 vs. 2000 grams	2.682*	500 vs. 2000 grams	6.478***
500 vs. 2500 grams	1.128	500 vs. 2500 grams	.376
1000 vs. 1500 grams	2.347*	1000 vs. 1500 grams	.866
1000 vs. 2000 grams	6.731***	1000 vs. 2000 grams	3.271**
1000 vs. 2500 grams	11.163***	1000 vs. 2500 grams	10.169***
1500 vs. 2000 grams	4.545***	1500 vs. 2000 grams	2.381*
1500 vs. 2500 grams	9.223***	1500 vs. 2500 grams	9.483***
2000 vs. 2500 grams	4.975***	2000 vs. 2500 grams	7.870***

* $.05 > P > .01$

** $.01 > P > .001$

*** $P < .001$

TABLE 6

"t" Comparisons of Weber Ratios for Various Forces Applied to the Buccal Surfaces of the Mandibular First Premolar

Buccal

Applied Force	"t" Value
100 vs. 200 grams	20.905***
100 vs. 500 grams	37.226***
100 vs. 1000 grams	41.493***
100 vs. 1500 grams	42.057***
100 vs. 2000 grams	40.390***
100 vs. 2500 grams	37.313***
200 vs. 500 grams	21.538***
200 vs. 1000 grams	28.074***
200 vs. 1500 grams	29.017***
200 vs. 2000 grams	26.353***
200 vs. 2500 grams	21.578***
500 vs. 1000 grams	7.591***
500 vs. 1500 grams	8.127***
500 vs. 2000 grams	4.746***
500 vs. 2500 grams	1.650
1000 vs. 1500 grams	00.000
1000 vs. 2000 grams	3.502**
1000 vs. 2500 grams	10.487***
1500 vs. 2000 grams	3.863***
1500 vs. 2500 grams	11.475***
2000 vs. 2500 grams	7.393***

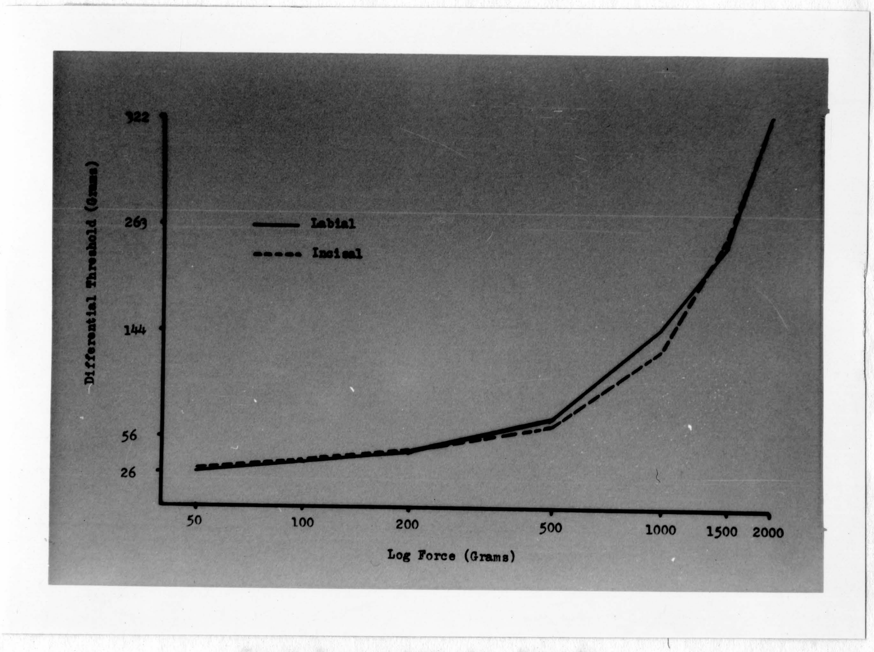
* $.05 > P > .01$

** $.01 > P > .001$

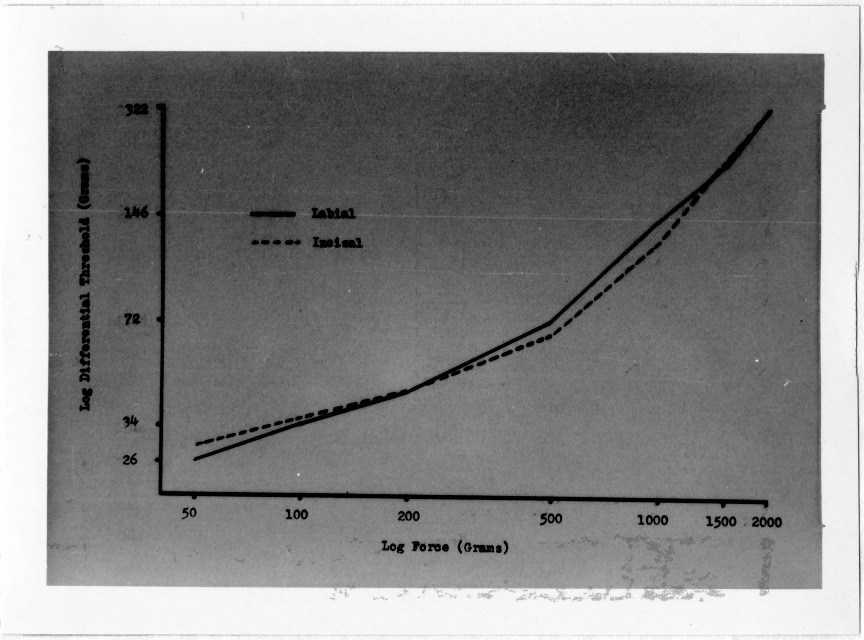
*** $P < .001$

FIGURE 7

Logarithmic-Logarithmic and Semi-Logarithmic Graphs of Differential Thresholds Plotted Against Forces Applied Along the Long Axis and 90° to the Long Axis of the Mandibular Central Incisor



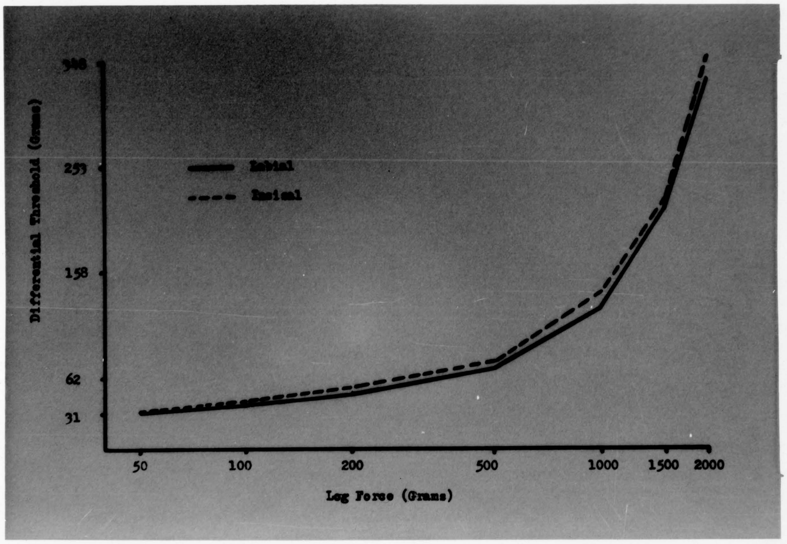
Semi-Logarithmic Graph



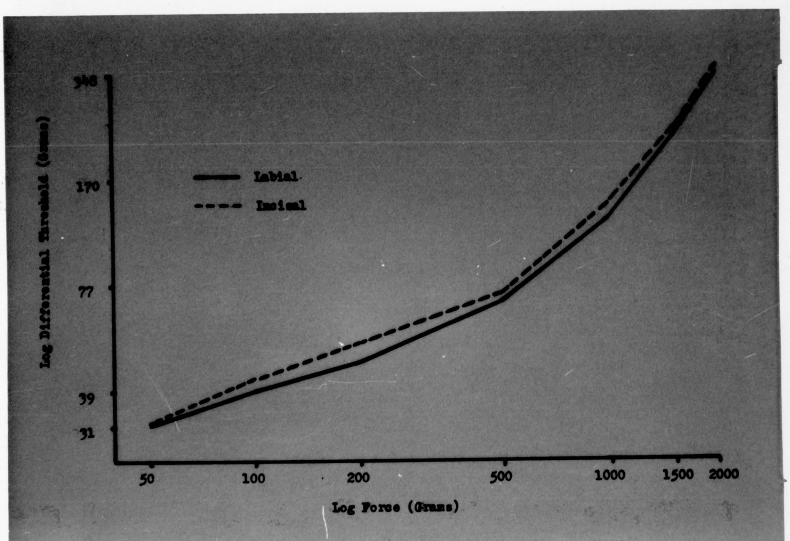
Logarithmic-Logarithmic Graph

FIGURE 8

Logarithmic-Logarithmic and Semi-Logarithmic Graphs of Differential Thresholds Plotted Against Forces Applied Along the Long Axis and 90° to the Long Axis of the Mandibular Lateral Incisor



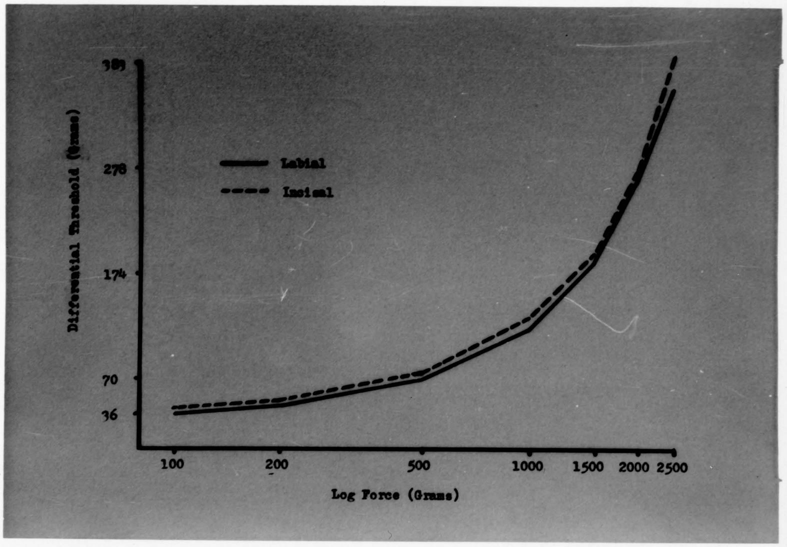
Semi-Logarithmic Graph



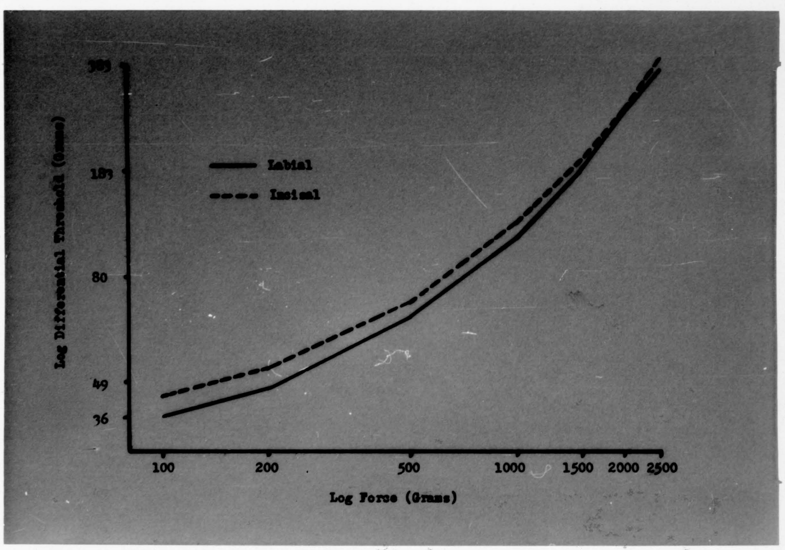
Logarithmic-Logarithmic Graph

FIGURE 9

Logarithmic-Logarithmic and Semi-Logarithmic Graphs of Differential Thresholds Plotted Against Forces Applied Along the Long Axis and 90° to the Long Axis of the Mandibular Canine



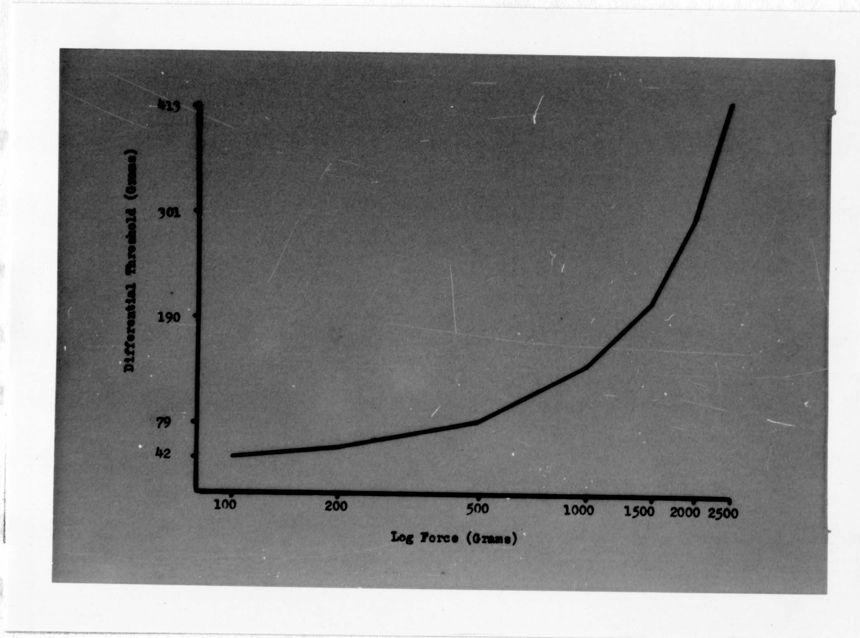
Semi-Logarithmic Graph



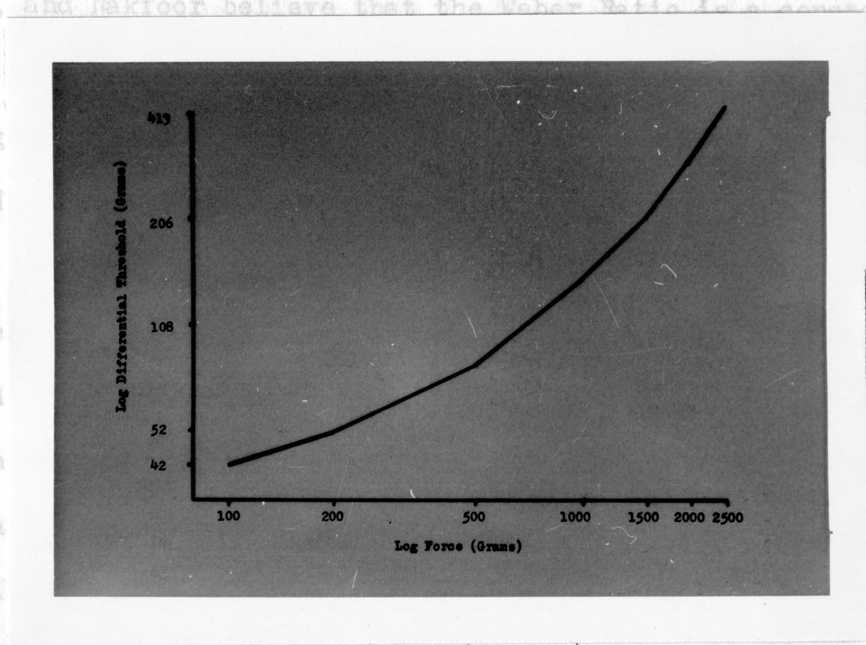
Logarithmic-Logarithmic Graph

FIGURE 10

Logarithmic-Logarithmic and Semi-Logarithmic Graphs of Differential Thresholds Plotted Against Forces Applied at 90° to the Long Axis of the Mandibular First Premolar



Semi-Logarithmic Graph



Logarithmic-Logarithmic Graph

CHAPTER V

DISCUSSION

Fechner's formulation of the Psychophysical Law, which states that the sensation increases as the logarithm of the intensity, first popularized the earlier studies conducted by Weber. In his work, Fechner assumed that the "just noticable difference" of sensation always contained the same number of sensation units, and thus the Weber Ratio remained a constant throughout the entire scale of sensory stimuli.

However, since Fechner's time many investigators have questioned the validity of the Weber Ratio being expressed as a constant over the entire range of the sensory scale. James, Hecht, Pieron, Guilford, Treisman, and Nakfoor believe that the Weber Ratio is a constant only over the intermediate ranges of intensity, and that near threshold or physiologically tolerable limits of intensity the ratio increases.

The results of this experiment are in agreement with the observations of these investigators. In all of the teeth tested, the Weber Ratios were higher at both the lower and upper extremes of the intensity scale. At the lower intensities of 50 grams, 100 grams, and 200 grams, discrimination was very poor, and the resultant Weber Ratios were much higher than those reported by Nakfoor for comparable forces applied to the maxillary central incisor. At the higher intensities of 2000 grams for the incisors, and 2500 grams for the canine and first premolar, the

Weber Ratios increased, but the values were not nearly as high as they were at the lower intensities. A possible explanation for this could be that the lower force values were very close to the threshold limits of the teeth tested, whereas, the higher applied forces were still within the physiologically tolerable ranges even though they were above the range where the Weber Ratio was relatively constant.

Kawamura and Watanabe tested the discriminatory ability of test subjects by having them bite down on stainless steel wires of small diameter placed between their maxillary and mandibular teeth. They established the Weber Ratio for the natural human dentition to be 0.1 in both the incisor and molar areas. In this study, the Weber Ratios varied between .117 and .153 in the intermediate ranges of intensity, and thus compared favorably to the findings of these men. One significant difference was that the findings of Kawamura and Watanabe were based on 100 per cent discrimination, while in the present study 70 per cent discrimination was satisfactory. If 100 per cent discrimination had been required in this study, the Weber Ratios undoubtedly would have been higher.

It should be pointed out that the experiment of Kawamura and Watanabe measured total proprioception, and was not confined to the proprioceptive impulses from the periodontal ligament as in the present study. Actually, they were testing the ability to evaluate free-way space rather than determining proprioception for the teeth.

In its original form Fechner's Law states that sensation increases as the logarithm of the stimulus intensity increases. This logarithmic expression of the Psychophysical Law can be equated mathematically as $S = A \log I + K$. Many opponents of this theory, most notably Stevens, feel that the relation between sensory intensity and stimulus intensity can be more accurately expressed as a power function. Stevens feels that the Psychophysical Law is best expressed as a power function of the general form $dS = k\ I^x$.

If the logarithmic equation of Fechner provides the better fit for the data of this experiment, then a semi-logarithmic plot should exhibit linearity for those forces that fall within the functional limits of the phenomenon. If the power function equation of Stevens better fits the data, then a logarithmic-logarithmic plot will best exhibit the desired linearity. When comparing the two plots, it is readily seen that the logarithmic-logarithmic plot exhibits better linearity in the functional range of the Psychophysical phenomenon for all teeth tested. (Figures 7, 8, 9, and 10). It is felt, from this, that the power function of Stevens, $dS = k\ I^x$, fits the data for this study better than the Fechner logarithmic equation.

The lower limits of the optimal range for the Psychophysical phenomenon for both incisors lies between 200 grams and 500 grams, while the upper limit occurs at about 1500 grams. The lower limit for the canine also was between 200 grams and 500 grams, while for the premolar it was located near 500 grams of applied force. In both of these teeth, the upper limits for the Weber Ratio was not as well defined, but was probably near the 2500 gram maximal force that was used in this experiment. Although the evidence indicates a fairly close linear relationship on the logarithmic-logarithmic plot between sensation intensity and stimulus intensity in these ranges, it should be noted that the linearity exhibited here is not as clearly demonstrated as in Nakfoor's study dealing with the maxillary incisor.

Based on the results of this study, one must conclude that the teeth tested did not exhibit directional sensitivity to the extent reported for the cat canine in studies by Pfaffman, and for the rabbit incisor in Ness' study. In all cases, labially and incisally applied forces had nearly the same range of discrimination with regard to the actual values in grams employed. This is in general agreement with the findings that Nakfoor reported on the maxillary central incisor, and would offer indirect evidence as to the location of the pressoreceptors in the periodontal ligament of human mandibular teeth. This lack of directional sensitivity supports in theory at least for humans the findings of Lewinsky and Stewart that the pressoreceptors are evenly distributed throughout the periodontal ligament, rather than being limited to the apical one-third of the root as reported by Kizior in his study of the cat.

Of the four teeth tested, the canine showed the greatest sensitivity to this force stimulation. This is in agreement with the findings of Starkie and Stewart, Kruger and Michel, and Cuozzo. Starkie and Stewart explain this by observing that the canine teeth are innervated by both the anterior and posterior alveolar plexi, rather than by one or the other as is true of the incisors (anterior plexus), or the premolars and molars (posterior plexus). Kruger and Michel state that the greater sensitivity of the canine teeth reflects a richer nerve innervation, and a greater usefullness of these teeth as a tactile organ at least in the cat. One could then argue that these results indicate an evolutionary retention, though these teeth do not function significantly as tactile organs in humans.

The first premolar exhibited the lowest sensitivity to tactile stimuli of any of the teeth tested. This finding would be in agreement with the results of Loewenstein and Rathkamp for pressure thresholds. In their study, pressure stimuli were applied to the incisal and occlusal surfaces of human teeth. In both the maxillary and mandibular teeth, the thresholds increased when going from the incisors to the posterior teeth. They felt that the higher thresholds observed on the posterior teeth was due to the greater surface area of the roots of these teeth without an accompanying increase in the number of nerve fibers innervating the periodontal ligament as is seen in the canine teeth.

CHAPTER VI

SUMMARY AND CONCLUSION

A method was described for testing proprioceptive discrimination in the human periodontal ligament. This method was used to test the ability of non-orthodontically treated adults to differentiate between similar forces applied to the mandibular central incisor, lateral incisor, canine, and first premolar.

It was found that the ability of subjects to discriminate differences between forces applied to these teeth was very poor when light forces of 50 grams, 100 grams, and 200 grams were used.

The optimal working range of the Psychophysical Phenomenon varied for the different teeth tested. For the incisors, the lower limit occurred between 200 grams and 500 grams, while the upper limit extended to approximately 1500 grams. For the canine, the lower limit of the law was found to rest between 200 grams and 500 grams. On the premolar the lower limit was close to 500 grams. For both the canine and premolar, the upper limits of Psychophysical Phenomenon was poorly defined, but probably was near 2500 grams of applied force.

The Weber Ratio for the periodontal ligament of human adults ranged between .125 and .153 of the standard force values between 500 grams and 1500 grams on the central and lateral incisors, .117 and .153 of the standard force values between 500 grams and 2500 grams on the canine, and .137 and .165 of the standard force values between 500 grams and 2500 grams on the first premolar.

The relation between sensory intensity and stimulus intensity in this experiment is best expressed by the power function equation of Stevens. This is stated mathematically as:

$$dS = k\ I^{x}.$$

The human periodontal ligament exhibited only slightly greater directional sensitivity on the incisal edge when the applied force was along the long axis of the tooth than on the labial surface when the applied force was directed at an angle of 90° to the long axis of the tooth. In some of the teeth, the labial surface was more sensitive than the incisal surface. It may be concluded from this that the pressoreceptors of the human periodontal ligament present an arrangement different from that seen in some experimental animals.

Of the four teeth tested, the mandibular canine demonstrated the greatest discriminability to pressure stimuli, while the first premolar was the least discriminative.

APPENDIX I

Measurement Values for Forces Applied 90° to Long Axis Expressed in Actual Values and Weber Ratios for the Mandibular Central Incisor

Sub-ject No.	50 gm. Gm.	50 gm. Ratio	100 gm. Gm.	100 gm. Ratio	200 gm. Gm.	200 gm. Ratio	500 gm. Gm.	500 gm. Ratio	1000 gm. Gm.	1000 gm. Ratio	1500 gm. Gm.	1500 gm. Ratio	2000 gm. Gm.	2000 gm. Ratio
1	15	.30	20	.20	25	.125	50	.10	75	.075	150	.10	250	.125
2	10	.20	20	.20	40	.20	75	.15	100	.10	200	.133	250	.125
3	20	.40	30	.30	40	.20	125	.25	200	.20	200	.133	300	.15
4	15	.30	25	.25	30	.15	50	.10	100	.10	200	.133	300	.15
5	30	.60	30	.30	30	.15	75	.15	125	.125	200	.133	300	.15
6	20	.40	40	.40	50	.25	75	.15	125	.125	250	.167	450	.225
7	20	.40	40	.40	50	.25	100	.20	125	.125	200	.133	300	.15
8	15	.30	20	.20	20	.10	75	.15	125	.125	175	.125	250	.125
9	20	.40	20	.20	20	.10	50	.10	75	.075	100	.067	200	.10
10	25	.50	50	.50	80	.40	150	.30	300	.30	500	.33	600	.30
11	20	.40	20	.20	30	.15	50	.10	100	.10	150	.10	200	.10
12	20	.40	25	.25	30	.15	50	.10	75	.075	150	.10	200	.10
13	20	.40	30	.30	30	.15	50	.10	100	.10	150	.10	250	.125
14	30	.60	40	.40	40	.20	50	.10	100	.10	150	.10	350	.175
15	25	.50	30	.30	30	.15	50	.10	100	.10	150	.10	200	.10
16	40	.80	60	.60	70	.35	100	.20	250	.25	400	.27	500	.25
17	40	.80	40	.40	50	.25	75	.15	100	.10	150	.10	300	.15
18	20	.40	30	.30	30	.15	75	.15	200	.20	300	.20	500	.25
19	40	.80	70	.70	80	.40	75	.15	100	.10	150	.10	250	.125
20	30	.60	70	.70	80	.40	125	.25	250	.25	500	.33	700	.35
21	40	.80	40	.40	60	.30	150	.30	300	.30	500	.33	500	.25
22	30	.60	30	.30	30	.15	75	.15	125	.125	175	.12	300	.15
23	30	.60	40	.40	50	.25	50	.10	100	.100	200	.133	300	.15
24	30	.60	30	.30	40	.20	50	.10	75	.075	150	.10	200	.10
25	30	.60	30	.30	40	.20	50	.10	125	.125	150	.10	200	.10
26	35	.70	30	.30	40	.20	50	.10	100	.10	150	.10	250	.125
27	5	.10	10	.10	10	.15	75	.15	50	.050	100	.067	150	.075
28	30	.60	30	.30	40	.20	50	.10	100	.10	200	.133	300	.15
29	40	.80	50	.50	60	.30	25	.05	125	.125	200	.133	350	.175
30	30	.60	30	.30	40	.20	50	.10	100	.10	150	.10	250	.125

APPENDIX II

Measurement Values for Forces Applied Parallel to Long Axis Expressed in Actual Values and Weber Ratios for the Mandibular Central Incisor

Subject No.	50 gm.		100 gm.		200 gm.		500 gm.		1000 gm.		1500 gm.		2000 gm.	
	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio
1	30	.60	20	.20	30	.15	50	.10	100	.10	200	.133	250	.125
2	30	.60	30	.30	40	.20	50	.10	100	.10	200	.133	250	.125
3	40	.80	20	.20	25	.125	50	.10	125	.125	250	.167	250	.125
4	15	.30	25	.25	30	.15	50	.10	100	.10	250	.167	300	.15
5	30	.60	30	.30	30	.15	75	.15	100	.10	250	.167	300	.15
6	30	.60	50	.50	50	.25	100	.20	150	.15	250	.167	400	.20
7	40	.80	50	.50	60	.30	75	.15	125	.125	200	.133	300	.15
8	20	.40	20	.20	30	.15	75	.15	150	.15	200	.133	300	.15
9	10	.20	20	.20	30	.15	50	.10	100	.10	150	.10	250	.125
10	30	.60	60	.60	70	.35	100	.20	200	.20	250	.167	350	.175
11	30	.60	30	.30	40	.20	75	.15	175	.175	300	.20	400	.20
12	25	.50	30	.30	40	.20	50	.10	75	.075	150	.10	200	.10
13	30	.60	30	.30	40	.20	50	.10	100	.10	150	.10	300	.15
14	30	.60	30	.30	40	.20	50	.10	100	.10	200	.133	400	.20
15	25	.50	20	.20	30	.15	50	.10	100	.10	150	.10	250	.125
16	25	.50	40	.40	40	.20	75	.15	100	.10	200	.133	350	.175
17	40	.80	40	.40	40	.20	50	.10	125	.125	200	.133	350	.175
18	20	.40	30	.30	30	.15	50	.10	125	.125	150	.10	350	.175
19	40	.80	50	.50	50	.25	75	.15	175	.175	300	.20	400	.20
20	40	.80	80	.80	90	.45	100	.20	200	.20	400	.267	650	.325
21	40	.80	70	.70	90	.45	150	.30	300	.30	450	.30	600	.30
22	20	.40	30	.30	40	.20	75	.15	150	.15	250	.167	350	.175
23	40	.80	40	.40	50	.25	50	.10	100	.10	150	.10	250	.125
24	40	.80	40	.40	50	.25	75	.15	150	.150	250	.167	400	.20
25	10	.20	20	.20	20	.10	50	.10	100	.10	150	.10	200	.10
26	30	.60	40	.40	40	.20	50	.10	100	.10	150	.10	250	.125
27	5	.10	10	.10	20	.10	50	.10	75	.075	100	.067	150	.075
28	35	.70	40	.40	40	.20	50	.10	100	.10	150	.10	250	.125
29	30	.60	40	.40	40	.20	50	.10	125	.125	200	.133	350	.175
30	30	.60	40	.40	40	.20	50	.10	100	.10	150	.10	200	.10

APPENDIX III

Measurement Values for Forces Applied 90° to Long Axis Expressed in Actual Values and Weber Ratios for the Mandibular Lateral Incisor

Sub-ject No.	50 gm.		100 gm.		200 gm.		500 gm.		1000 gm.		1500 gm.		2000 gm.	
	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio
1	15	.30	20	.20	30	.15	50	.10	75	.075	175	.117	250	.125
2	30	.60	25	.25	30	.15	75	.15	125	.125	150	.10	250	.125
3	40	.80	30	.30	40	.20	75	.15	100	.10	150	.10	350	.175
4	30	.60	25	.25	40	.20	50	.10	75	.075	200	.133	300	.15
5	40	.80	70	.70	80	.40	100	.20	100	.10	150	.10	250	.125
6	40	.80	70	.70	70	.35	75	.15	200	.20	400	.267	600	.30
7	20	.40	40	.40	40	.20	50	.10	100	.10	200	.133	350	.175
8	15	.30	20	.20	30	.15	75	.15	100	.10	150	.10	250	.125
9	20	.40	20	.20	20	.10	50	.10	75	.075	100	.067	150	.075
10	40	.80	70	.70	90	.45	150	.30	200	.20	400	.267	600	.30
11	15	.30	30	.30	50	.25	50	.10	100	.10	150	.10	200	.10
12	30	.60	30	.30	40	.20	50	.10	75	.075	150	.10	200	.10
13	30	.60	40	.40	50	.25	100	.20	150	.15	200	.133	300	.15
14	30	.60	30	.30	40	.20	50	.10	100	.10	200	.133	350	.175
15	40	.80	20	.20	30	.15	50	.10	100	.10	150	.10	200	.10
16	30	.60	50	.50	60	.30	75	.15	200	.20	350	.233	500	.25
17	40	.80	50	.50	80	.40	100	.20	150	.15	200	.133	350	.175
18	30	.60	30	.30	50	.25	75	.15	200	.20	250	.167	450	.225
19	40	.80	40	.40	50	.25	50	.10	100	.10	200	.133	250	.125
20	40	.80	70	.70	70	.35	125	.25	250	.25	400	.267	650	.325
21	40	.80	70	.70	80	.40	150	.30	300	.30	450	.30	500	.25
22	30	.60	30	.30	40	.20	75	.15	100	.10	200	.133	300	.15
23	40	.80	40	.40	50	.25	75	.15	100	.10	150	.10	300	.15
24	20	.40	30	.30	35	.175	50	.10	75	.075	150	.10	300	.15
25	30	.60	30	.30	40	.20	50	.10	100	.10	100	.067	200	.10
26	40	.80	40	.40	50	.25	75	.15	150	.15	200	.133	400	.20
27	5	.10	10	.10	10	.05	25	.05	50	.050	100	.067	150	.075
28	30	.70	40	.40	50	.25	50	.10	100	.10	200	.133	350	.175
29	40	.80	50	.50	50	.25	50	.10	100	.10	150	.10	250	.125
30	30	.60	40	.40	50	.25	50	.10	100	.10	200	.133	300	.15

APPENDIX IV

Measurement Values for Forces Applied Parallel to Long Axis Expressed in Actual Values and Weber Ratios for the Mandibular Lateral Incisor

Sub-ject No.	50 gm. Gm.	Ratio	100 gm. Gm.	Ratio	200 gm. Gm.	Ratio	500 gm. Gm.	Ratio	1000 gm. Gm.	Ratio	1500 gm. Gm.	Ratio	2000 gm. Gm.	Ratio
1	15	.30	30	.30	50	.25	50	.10	75	.075	100	.067	250	.125
2	30	.60	50	.50	40	.20	75	.15	125	.125	125	.083	300	.15
3	40	.80	40	.40	40	.20	50	.10	150	.15	240	.167	300	.15
4	15	.30	30	.30	40	.20	50	.10	100	.10	250	.167	300	.15
5	40	.80	40	.40	40	.20	75	.15	125	.125	175	.117	250	.125
6	40	.80	60	.60	70	.35	150	.30	250	.250	500	.33	700	.35
7	40	.80	60	.60	80	.40	100	.20	200	.20	250	.167	350	.175
8	15	.30	20	.20	40	.20	50	.10	100	.10	150	.10	250	.125
9	20	.40	30	.30	30	.15	50	.10	100	.10	150	.10	250	.125
10	40	.80	70	.70	100	.50	150	.30	250	.25	350	.233	500	.25
11	25	.50	40	.40	40	.20	75	.15	200	.20	350	.233	450	.225
12	30	.60	30	.30	30	.15	50	.10	100	.10	150	.10	200	.10
13	30	.60	40	.40	50	.25	100	.20	125	.125	175	.117	300	.15
14	35	.70	50	.50	50	.25	100	.20	200	.20	300	.20	500	.25
15	40	.80	40	.40	50	.25	50	.10	100	.10	200	.133	300	.15
16	30	.60	40	.40	50	.25	75	.15	150	.15	250	.167	450	.225
17	40	.80	70	.70	100	.50	100	.20	100	.10	150	.10	300	.15
18	20	.40	20	.20	30	.15	50	.10	100	.10	150	.10	250	.125
19	40	.80	40	.40	70	.35	100	.20	200	.20	300	.20	400	.20
20	40	.80	70	.70	80	.40	100	.20	150	.15	350	.233	600	.30
21	40	.80	60	.60	80	.40	100	.20	300	.30	300	.20	600	.30
22	30	.60	50	.50	60	.30	75	.15	125	.125	250	.167	450	.225
23	40	.80	50	.50	60	.30	75	.15	100	.10	200	.133	300	.15
24	30	.60	40	.40	60	.30	75	.15	150	.150	250	.167	300	.15
25	20	.40	20	.20	30	.15	50	.10	100	.10	150	.10	200	.10
26	40	.80	40	.40	50	.20	75	.15	100	.10	200	.133	350	.175
27	15	.30	15	.15	20	.10	50	.10	50	.05	100	.067	150	.075
28	30	.60	40	.40	40	.20	50	.10	100	.10	200	.133	300	.15
29	40	.80	50	.50	60	.30	75	.15	100	.10	200	.133	300	.15
30	40	.80	50	.50	50	.25	75	.15	100	.10	150	.10	300	.15

APPENDIX V

Measurement Values for Forces Applied 90° to Long Axis Expressed in Actual Values and Weber Ratios for the Mandibular Canine

Subject No.	100 gm.		200 gm.		500 gm.		1000 gm.		1500 gm.		2000 gm.		2500 gm.	
	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio
1	15	.15	20	.10	50	.10	75	.075	100	.067	200	.10	250	.10
2	30	.30	30	.15	50	.10	100	.10	150	.10	300	.15	400	.16
3	20	.20	40	.20	75	.15	100	.10	150	.10	250	.125	300	.12
4	20	.20	20	.10	50	.10	100	.10	200	.133	300	.15	300	.12
5	70	.70	30	.15	50	.10	75	.075	200	.133	250	.125	250	.10
6	70	.70	90	.45	100	.20	200	.20	300	.20	400	.20	500	.20
7	40	.40	60	.30	75	.15	150	.15	200	.133	200	.10	300	.12
8	40	.40	50	.25	150	.30	250	.25	400	.267	500	.25	600	.24
9	20	.20	30	.15	50	.10	75	.075	150	.10	200	.10	250	.10
10	50	.50	70	.35	150	.30	200	.20	250	.167	300	.15	500	.20
11	25	.25	40	.20	50	.10	100	.10	150	.10	250	.125	350	.14
12	40	.40	50	.25	50	.10	100	.10	150	.10	200	.10	250	.10
13	30	.30	30	.15	50	.10	75	.075	100	.067	150	.075	250	.10
14	20	.20	30	.15	50	.10	100	.10	150	.10	200	.10	250	.10
15	40	.40	30	.15	50	.10	100	.10	150	.10	250	.125	300	.12
16	30	.30	40	.20	75	.15	150	.15	250	.167	350	.175	500	.20
17	30	.30	40	.20	50	.10	100	.10	150	.10	200	.10	250	.10
18	30	.30	30	.15	50	.10	100	.10	250	.167	400	.20	500	.20
19	50	.50	70	.35	100	.20	100	.10	150	.10	250	.125	300	.12
20	50	.50	70	.35	100	.20	125	.125	200	.133	350	.175	500	.20
21	60	.60	80	.40	150	.30	200	.20	250	.167	350	.175	450	.18
22	50	.50	40	.20	50	.10	100	.10	150	.10	200	.10	300	.12
23	40	.40	50	.25	75	.15	100	.10	150	.10	200	.10	300	.12
24	35	.35	40	.20	50	.10	150	.15	200	.133	300	.15	450	.18
25	20	.20	20	.20	50	.10	100	.10	150	.10	200	.10	250	.10
26	30	.30	50	.25	75	.15	150	.15	200	.133	300	.15	500	.20
27	10	.10	10	.05	25	.05	50	.05	100	.067	150	.075	200	.08
28	30	.30	40	.20	50	.10	75	.175	150	.10	200	.10	300	.12
29	40	.30	50	.25	75	.15	125	.125	175	.117	250	.125	400	.16
30	30	.30	40	.20	50	.10	75	.075	150	.10	200	.10	300	.12

Measurement Values for Forces Applied Parallel to Long Axis Expressed in Actual Values and Weber Ratios for the Mandibular Canine

Subject No.	100 gm. Gm.	100 gm. Ratio	200 gm. Gm.	200 gm. Ratio	500 gm. Gm.	500 gm. Ratio	1000 gm. Gm.	1000 gm. Ratio	1500 gm. Gm.	1500 gm. Ratio	2000 gm. Gm.	2000 gm. Ratio	2500 gm. Gm.	2500 gm. Ratio
1	20	.20	20	.10	50	.10	100	.10	150	.10	200	.10	250	.10
2	50	.50	70	.35	75	.15	150	.15	250	.167	350	.175	400	.16
3	20	.20	30	.15	75	.15	125	.125	200	.133	250	.125	350	.14
4	50	.50	30	.15	50	.10	75	.075	150	.10	200	.10	300	.12
5	80	.80	50	.25	50	.10	50	.05	200	.133	250	.125	250	.10
6	50	.50	70	.35	125	.25	250	.25	400	.267	400	.20	600	.24
7	60	.60	70	.35	100	.20	200	.20	300	.20	400	.20	500	.20
8	20	.20	30	.15	50	.10	125	.125	150	.10	200	.10	300	.12
9	30	.30	30	.15	50	.10	75	.075	150	.10	200	.10	250	.10
10	50	.50	80	.40	150	.30	200	.20	200	.133	300	.15	450	.18
11	40	.40	50	.25	50	.10	75	.075	150	.10	250	.125	350	.14
12	30	.30	40	.20	50	.10	75	.075	150	.10	200	.10	250	.10
13	30	.30	40	.20	50	.10	75	.075	150	.10	200	.10	250	.10
14	30	.30	50	.25	100	.20	200	.20	300	.20	450	.225	650	.26
15	40	.40	50	.25	75	.15	150	.15	150	.10	250	.125	350	.14
16	50	.50	60	.30	100	.20	200	.20	300	.20	450	.225	600	.24
17	50	.50	50	.25	100	.20	125	.125	150	.10	250	.125	350	.14
18	30	.30	30	.15	50	.10	75	.075	250	.167	350	.175	400	.16
19	50	.50	60	.30	100	.20	150	.15	200	.133	250	.125	350	.14
20	40	.40	60	.30	100	.20	125	.125	200	.133	300	.15	500	.20
21	80	.80	90	.45	150	.30	200	.20	350	.233	400	.20	650	.26
22	60	.60	80	.40	100	.20	150	.15	150	.10	250	.125	450	.18
23	40	.40	50	.25	50	.10	100	.10	150	.10	200	.10	250	.10
24	50	.50	60	.30	75	.15	150	.15	200	.133	300	.15	450	.18
25	20	.20	20	.10	50	.10	100	.10	100	.067	200	.10	250	.10
26	40	.40	50	.25	75	.15	150	.15	150	.10	250	.125	400	.16
27	20	.20	30	.15	50	.10	100	.10	150	.10	200	.10	250	.10
28	30	.30	40	.20	50	.10	100	.10	150	.10	200	.10	350	.14
29	40	.40	50	.25	75	.15	125	.125	200	.133	250	.125	350	.14
30	30	.30	40	.20	50	.10	100	.10	150	.10	200	.10	350	.14

APPENDIX VII

Measurement Values for Forces Applied 90° to Long Axis Expressed in Actual Values and Weber Ratios for the Mandibular First Premolar

Subject No.	100 gm.		200 gm.		500 gm.		1000 gm.		1500 gm.		2000 gm.		2500 gm.	
	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio	Gm.	Ratio
1	15	.15	30	.15	50	.10	75	.075	125	.083	200	.10	300	.12
2	40	.40	50	.25	75	.15	200	.20	250	.167	300	.15	300	.12
3	20	.20	40	.20	75	.15	125	.125	200	.133	300	.15	400	.16
4	20	.20	40	.20	50	.10	100	.10	150	.10	200	.10	250	.10
5	80	.80	100	.50	100	.20	150	.15	250	.167	300	.15	400	.16
6	80	.80	100	.50	150	.30	200	.20	250	.167	300	.15	500	.20
7	40	.40	60	.30	100	.20	150	.15	250	.167	300	.15	400	.16
8	40	.40	50	.25	100	.20	250	.25	500	.33	600	.30	800	.32
9	40	.40	30	.15	50	.10	100	.10	150	.10	200	.10	250	.10
10	50	.50	60	.30	100	.20	200	.20	300	.20	400	.20	500	.20
11	30	.30	40	.20	75	.15	100	.10	150	.10	250	.125	350	.14
12	30	.30	40	.20	50	.10	100	.10	150	.10	200	.10	250	.10
13	40	.40	40	.20	50	.10	75	.075	125	.083	200	.10	350	.14
14	20	.20	20	.10	50	.10	100	.10	150	.10	200	.10	500	.20
15	40	.40	30	.15	75	.15	150	.15	250	.167	350	.175	450	.18
16	60	.60	70	.35	100	.20	200	.20	350	.233	500	.25	700	.28
17	40	.40	40	.20	50	.10	100	.10	150	.10	200	.10	300	.12
18	30	.30	40	.20	75	.15	100	.10	150	.10	250	.125	450	.18
19	40	.40	60	.30	50	.10	125	.125	200	.133	250	.125	300	.12
20	80	.80	100	.50	200	.40	300	.30	400	.267	500	.25	700	.28
21	80	.80	90	.45	100	.20	125	.125	250	.167	350	.175	500	.20
22	60	.60	70	.35	100	.20	150	.15	200	.133	350	.175	450	.18
23	40	.40	40	.20	50	.10	100	.10	200	.133	250	.125	350	.14
24	40	.40	60	.30	125	.25	175	.175	250	.167	350	.175	400	.16
25	20	.20	20	.10	50	.10	100	.10	200	.133	250	.125	400	.16
26	35	.35	60	.30	100	.20	175	.175	250	.167	350	.175	500	.20
27	15	.15	20	.10	50	.10	50	.05	100	.067	150	.075	200	.08
28	40	.40	50	.25	75	.15	125	.125	.75	.117	250	.125	400	.16
29	40	.40	50	.25	50	.10	100	.10	175	.117	250	.125	400	.16
30	40	.40	50	.25	75	.15	100	.10	150	.10	200	.10	300	.12

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APPROVAL SHEET

The thesis submitted by Dr. John G. Bonaguro has been read and approved by members of the Department of Oral Biology.

The final copies have been examined by the Director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

5/20/68

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